



Artificial Immune System for Recognizing Patterns

This method offers robust performance in analysis of large sets of data.

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A method of recognizing or classifying patterns is based on an artificial immune system (AIS), which includes an algorithm and a computational model of nonlinear dynamics inspired by the behavior of a biological immune system. The method has been proposed as the theoretical basis of the computational portion of a star-tracking system aboard a spacecraft. In that system, a newly acquired star image would be treated as an antigen that would be matched by an appropriate antibody (an entry in a star catalog). The method would enable rapid convergence, would afford robustness in the face of noise in the star sensors, would enable recognition of star images acquired in any sensor or spacecraft orientation, and would not make an excessive demand on the computational resources of a typical spacecraft. Going beyond the star-tracking application, the AIS-based pattern-recognition method is potentially applicable to pattern-recognition and classification processes for diverse purposes — for example, reconnaissance, detecting intruders, and mining data.

This AIS method is capable of efficient analysis of large sets of data, including sets that are characterized by high dimensionality and/or are ac-

quired over long time intervals. When the method is used for unsupervised or supervised classification, the amount of computation scales linearly with the number of dimensions and offers performance that is both (a) nearly independent of the total size of the set of data and (b) equal to or better than the performances of traditional clustering methods. When used for pattern recognition, the method efficiently finds appropriate matches in the data. The method enables efficient classification of a high-dimensional set of data in a single pass through the data, and quickly flags outliers in much the same way as the human immune system produces antibodies to invading antigens.

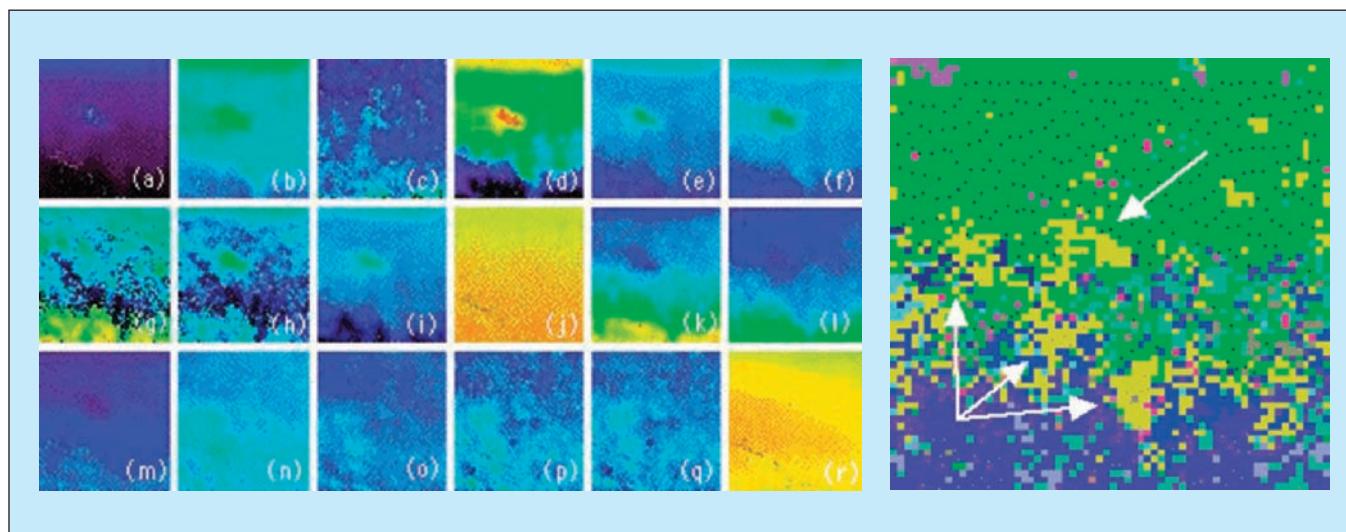
The AIS model in this method is embodied in a set of partial differential equations that approximate some aspects of the dynamics of a network of immune-system B cells:

$$\frac{\partial b_i}{\partial t} = s + b_i \left[\frac{p\theta}{\theta + b_i} f(h_i, h'_i) + K_{iA} - d \right]$$

where b_i is the number of cells of clone i , t is time, s is a rate of influx, p is a maximal growth rate, θ is a growth clone-size threshold, $f(h_i, h'_i)$ is a cell activation function, h_i is a binding field, h'_i is a cross-link-

ing field, K_{iA} is a measure of the affinity of a clone- i antibody for the antigen (the pattern to be recognized), and d is a death rate. The functions $f(h_i, h'_i)$, h_i , and h'_i are defined by additional equations that must be omitted here for the sake of brevity. Suffice it to say that the cell activation function, $f(h_i, h'_i)$, depends on the binding between the B-cell populations in the network. Cells having greater affinity with the incoming pattern (cells representing closer matches to the pattern) clone themselves (with or without mutation) faster than do those having lesser affinities (representing poorer matches).

The unsupervised classification process for this model starts with a single sequential presentation of the data to a randomly initialized set of cell populations. As a result of this mode of presentation, the amount of computation in the classification process is of the order of a number proportional to the number of dimensions of the input data. An affinity radius around each incoming pattern is used to cull the number of clone populations that respond each time. The system is allowed to evolve in time, and the clone population that survives is used as the class for each pattern. Typically, 10 to 20 computational cycles are all that are needed for convergence for each incoming item.



Spectral Images and Attribute Images derived from spectral images were generated from images of the Marquesas Islands acquired by a spaceborne imaging spectrometer in 18 wavelength bands at 36-km resolution. AIS classification of the data of the 18 images yielded an image in which Islands can be discerned more easily.

The method has been demonstrated by applying it to a high-dimensional data set representing images, synthesized from images acquired by a spaceborne imaging spectrometer in 18 wavelength bands, that show various attributes of the Marquesas Islands and vicinity (see figure). Details of

individual islands are difficult to discern in any one of the images, but after classification of the image data by the present AIS method, the dominant island groups can be discerned more easily.

This work was done by Terrance Huntsberger of Caltech for NASA's Jet Propulsion

Laboratory. Further information is contained in a TSP (see page 1).

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (818) 393-2827. Refer to NPO-40256.

Computing the Thermodynamic State of a Cryogenic Fluid

A quasi-steady-state thermodynamical model is iterated over time steps.

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The Cryogenic Tank Analysis Program (CTAP) predicts the time-varying thermodynamic state of a cryogenic fluid in a tank or a Dewar flask. CTAP is designed to be compatible with EASY5x, which is a commercial software package that can be used to simulate a variety of processes and equipment systems.

The need for CTAP or a similar program arises because there are no closed-form equations for the time-varying thermodynamic state of the cryogenic fluid in a storage-and-supply system. Manual calculations cannot incorporate all the pertinent variables and provide only steady-state solutions of limited accuracy. The heat energy flowing into and out of the system, the inflow and outflow of fluid, the thermal capacitance and elasticity of the storage vessel, and the thermodynamic properties of the cryogenic fluid at each instant of time are needed. In other words, to define the time varying state of the cryogenic fluid, it is necessary to calculate all the pertinent variables and iterate quasi-steady-state solutions at successive instants of time. It is impractical to attempt to do this without the help of a computer program.

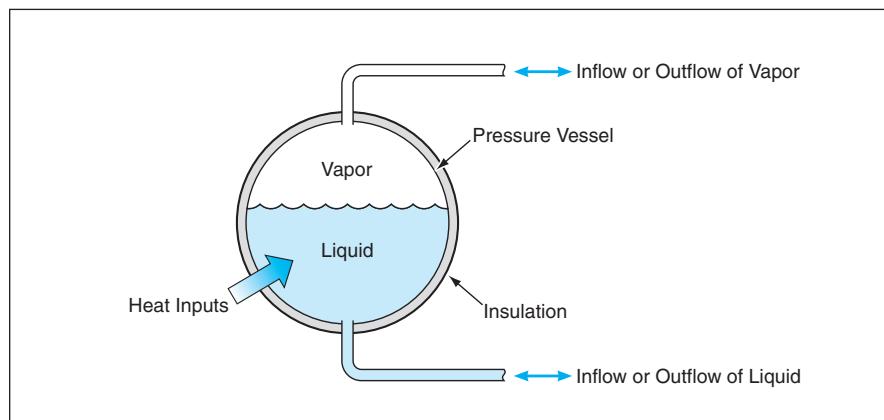
The basic tank system (see figure) modeled in CTAP consists of a pressure

vessel (the tank) that contains the cryogen; the insulation on the tank; the tank supports; and the fill, vent, and outflow tubes. The thermodynamic system is considered to be bounded by the outside surface of the pressure vessel, with provisions for flow of both liquid and gas into or out of the tank. The volume of the tank is treated as a variable to account for contraction and expansion of the pressure vessel with changes in pressure.

The mathematical model implemented in CTAP is a first-order differential equation for the pressure as a function of time. The equation is derived as a quasi-steady-state expression of the first law of thermodynamics for the system regarded as closed and isothermal. The equation includes terms for the parasitic leakage of heat through the insulation, for pressurization energy (supplied by heaters) to be added to the tank fluid, for expulsion of liquid or vapor, for the thermal capacitance of the tank wall, and for stretching of the tank under pressure. CTAP incorporates fluid-property subroutines based on equations of state developed at the National Institute of Standards and Technology. At present, the fluids represented in CTAP are hydrogen and oxygen.

CTAP is set up as a large subroutine to be called from within EASY5x. CTAP requires 28 input variables and returns 12 values for use in execution of EASY5x. The input variables define the fluid (oxygen or hydrogen), the initial state of the fluid, the tank and its parameters, the thermal environment, and the fluid scenario (defined next). The user can select any one of the following 12 options or fluid scenarios:

1. Program calculates rates of boil-off or expulsion for a supercritical fluid at constant pressure.
2. Program calculates rate of expulsion of liquid at constant pressure.
3. Program calculates rate of expulsion of vapor at constant pressure.
4. Program calculates the rate of increase of pressure under a condition of tank lockup.
5. Program calculates the rates of inflow of heat required for a given mass flow rate of supercritical fluid at constant pressure.
6. Program calculates the rates of inflow of heat required for a given mass flow rate of liquid at constant pressure.
7. Program calculates the rates of inflow of heat required for a given mass flow rate of vapor at constant pressure.
8. Program simulates tank blowdown — the expulsion of initially supercritical fluid from the tank. This calculation includes effects of stretching of the tank under pressure.
9. Program calculates variable-pressure expulsion of liquid under heater and mass-flow conditions specified by the user.
10. Program calculates variable-pressure expulsion of vapor under heater and mass-flow conditions specified by the user.
11. Program calculates heat loss through thermodynamic vent system.
12. Program calculates pressure rise in the tank from helium pressurant.



A Cryogenic Fluid and Tank, taken together as a time-varying system, are modeled in CTAP by a quasi-steady-state differential equation based on the first law of thermodynamics.